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A lime based mortar for thermal insulation of medieval church vaults

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Abstract – *A new mortar for thermal insulation of medieval church vaults was tested in a full scale experiment in Annisse Church, DK. The mortar consists of perlite, a highly porous aggregate, mixed with slaked lime. These materials are compatible with the fired clay bricks and the lime mortar joints. The lambda-value of the insulation mortar is 0.08 W/m K or twice the lambda-value for mineral wool. The water vapour permeability is equal to a medieval clay brick, and it has three times higher capacity for liquid water absorption. The mortar was applied to the top side of the vaults in a thickness of 10 cm, and covered by 10 mm lime plaster, reinforced with cattle hair. This assembly can carry the weight of a person, working with maintenance of the roof. Climate measurements confirmed excellent properties in regards to both moisture transport and thermal insulation. Condensation did not occur at any time, despite a water vapour pressure gradient up to 500 Pa between the nave and attic. There was no reduction in energy consumption the first winter, possibly due to the increased heat loss related to the drying of the mortar.*

Keywords – Church vault, thermal insulation, perlite mortar, vapour permeability

1. INTRODUCTION

1.1 BACKGROUND

There are 1700 medieval churches in Denmark, and many of these have brick vaults. The thickness of the vaults is usually only 12 – 15 cm, so the heat loss through this building component in winter is significant. The temperature in the attic is close to the outside temperature due to a high infiltration rate. In a permanently heated church the heat transmission through the vaults is half the total heat consumption. There is a large potential for reducing the heat loss through this building component. Computer modelling has indicated a possible saving of 30 – 40 % of the energy consumption.

Thermal insulation has not been permitted until now in respect for the antiquarian value. Modern materials made of mineral fibres or aerated concrete are not appropriate for restoration and repair of medieval masonry. There has also been speculation about the effect on water vapour transport through the vault and the risk of condensation inside the insulation or at the interface. Any thermal insulation should allow both liquid and vapour transport, and membranes should not be implemented. Salt contaminated vaults should not have thermal insulation due to the risk of salt decay. The vaults double curved geometry is also a challenge for thermal insulation. It is difficult to adapt sheets of mineral wool or porous silicate blocks to the surface without air gaps. Granulate insulation cannot adhere to the steep slope and will eventually end up in the vault pockets. To overcome these difficulties it is better to cast the insulation in situ and not use prefabricated materials. The insulation should be stiff enough to resist the weight of a person working with maintenance of the roof. Tests of thermal insulating plasters have been reported by several authors [1,2] but so far not related to church vaults.

1.2 ANNISSE CHURCH

A test of vault insulation was performed in Annisse Church, located in northern Zeeland, DK. The nave and chancel date to the 12th century and have lime washed stone walls. The cross arched vaults were constructed around 1400 with fired clay bricks and lime mortar. The tiled roof and the timber construction are from 1967. The total floor area of the nave and chancel is app. 120 m^2 and the volume is app. 500 m^3. The church has electric heating with heating elements mounted in the pews and on the walls

Figure 1. Interior view of the nave and the attic in Annisse Church

2. MATERIALS AND TECHNIQUES

2.1 PERLITE MORTAR

A new insulation mortar was developed to meet the demands listed above. It is a mixture of slaked lime and perlite grains in the dry volumetric ratio of 1:6. Approximately one part of water is added for workability. Perlite is manufactured by heating volcanic sand to 900 °C, by which the grains expands to a highly porous silicate substance. A grain size of 1 – 6 mm was used for the mortar. The material properties were tested in the laboratory and the most important parameters are listed below. Computer modelling indicated that the mortar would fulfil the requirements mentioned above [3].

Table 1. Material properties

material	**properties**			
	Density *(kg/m^3)*	*Thermal conductivity* *λ (W/m K)*	*Capillary suction* *k (kg/m^2 √s)*	*Water vapour permeability* *δ (kg x10^{-12}/m s Pa)*
Perlite mortar	390	0.08	0.86	35
Brick	1700	0.5	0.3	30

2.2 APPLICATION ON VAULT

The materials were prepared on site in a horizontal mixer. The lime was added to the perlite as slurry and blended gently for 30 sec. The top side of the vault had lime slurry applied first to improve the adhesion. The plaster was laid out with a trowel in one layer of 100 mm thickness. A distance of 50 mm was kept to the timber roof construction. After some days of initial setting, 10 mm lime plaster with natural fibre reinforcement was applied. This assembly would improve the load bearing capacity of the mortar. A preliminary test area was prepared in April 2014 in the north web of the second nave vault. The remaining vaults were insulated in September and October 2015.

2.3 CLIMATE MONITORING

Climate monitoring was initiated in March 2014. The temperature and relative humidity was measured in the nave and in the attic every hour, using TinyTag2 data loggers with integrated sensors. This device has a capacitive sensor for RH with an accuracy of +/- 3 %RH in the range 0-100 %RH. In august 2014 the monitoring was extended to the vault structure. External sensors for temperature and relative humidity were installed in the insulation mortar, in the vault below the insulation, and in the adjacent vault without insulation. Only climate data for the last year is presented below.

3. RESULTS AND DISCUSSION

3.1 TEMPERATURE

The temperature in each monitoring position is given in fig. 3. The temperature in the nave (red) was down to 15 ºC in winter and up to 25 °C in summer. The daily variation of 2-3 °C was mainly due to short heating events in winter and solar gain in summer. The annual temperature variation in the attic was from – 5 °C in winter up to 30 °C in summer. The attic was colder than the nave most of the year, except in summer, where solar radiation heated up the tiled roof. The temperature within the vault structure was always between the inside and outside. The insulated vault (green) was warmer than the vault without insulation (blue) until the beginning of October. After this vault was insulated, the temperature was almost the same in the two vaults for the rest of the period.

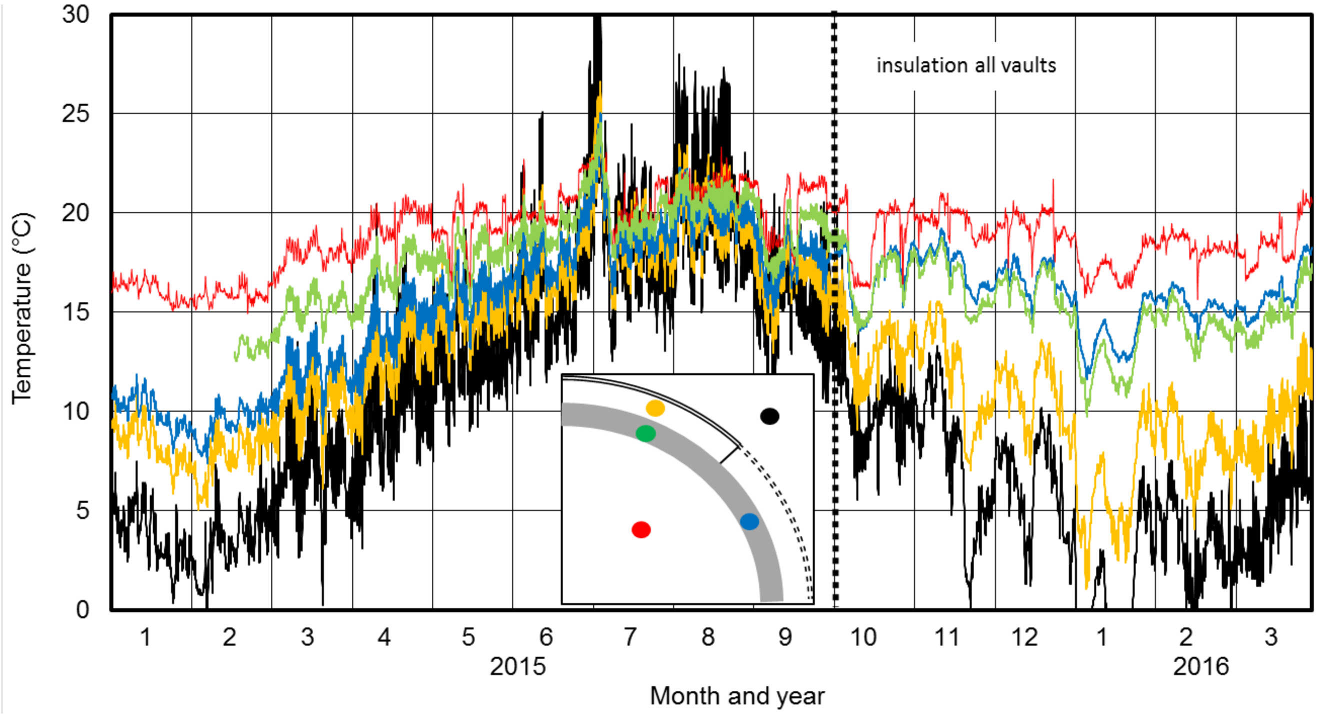

Figure 3. Temperature measurements

3.2 RELATIVE HUMIDITY

The relative humidity (RH) in each monitoring position is given in fig. 4. The RH in the attic (black) was higher than the RH in the nave (red) most of the year. Episodes of lower RH in the attic occurred during the spring and in summer. The RH in the vault below the insulation (green) was close to the RH in the nave most of the year. The insulation mortar (yellow) had an RH between the nave and the attic al year, except for a period in September. At this point there was a sudden increase in RH from 70 % to 90 % within 48 hours. The increase in RH coincided with a sudden fall in temperature of 6-8 °C, imposed by a change of the outside temperature. This illustrates that short events of high RH can occur in the insulation mortar. Condensation will only take place if the temperature drop is large enough, but this is quite unusual in Denmark´s mild coastal climate. The RH gradually decreased during the next four weeks and ended at 70 % at the beginning of October. The RH in the vault without insulation was between that in the nave and the attic until October. When insulation mortar was applied to this vault, the RH instantly rose to 100 % and stayed there for the rest of the year. From the beginning of January the RH decreased gradually and reached 80 %RH by the end of March. The RH in the nave was influenced by evaporation from the vaults. This gave an opportunity to test the effect of a large water vapour pressure gradient.

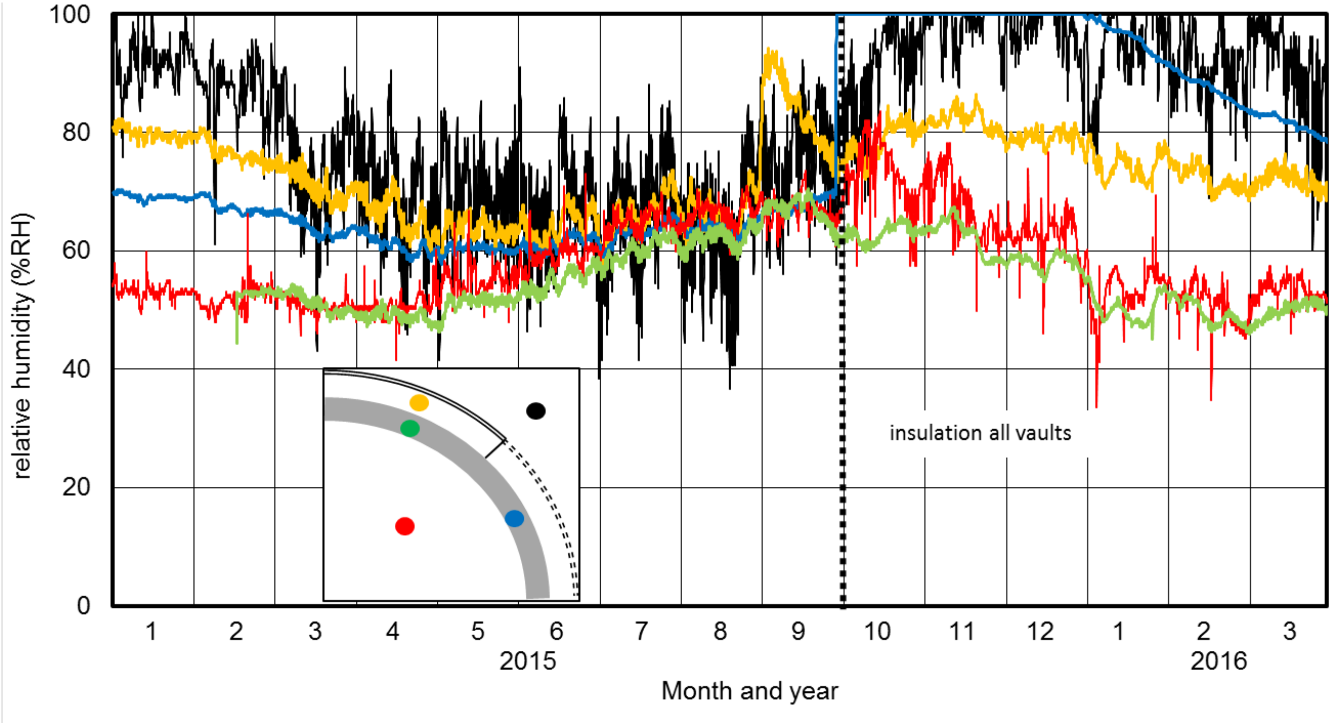

Figure 4. Relative humidity measurements

3.3 WATER VAPOUR PRESSURE

The water vapour pressure (VP) in each of the monitoring positions was calculated from the measured data of temperature and RH and given in fig. 5. The diagram shows the moving average over seven days. From January to September the VP was 200 – 300 Pa higher in the nave than in the attic. The VP in the vault and in the insulation mortar was between the nave and the attic for the first months. From April the VP in the vault approached the VP in the attic, and from June and until September there was almost no difference.

From the beginning of October there was an instant increase in VP in the vault, where insulation mortar was applied. The rise in VP was due to the migration of liquid water from the mortar into the vault below. The rise in VP influenced the VP in the nave, so the difference to the attic was up to 500 Pa. There was very little influence on the VP in the test vault, which remained close to the VP in the attic. This shows that the insulation did not reduce the vapour diffusion through the vault significantly. Even such a considerable vapour pressure gradient did not impose condensation in the insulation mortar. The VP in the attic was close to the outside VP, and no condensation was observed in this part of the building, despite of the high RH.

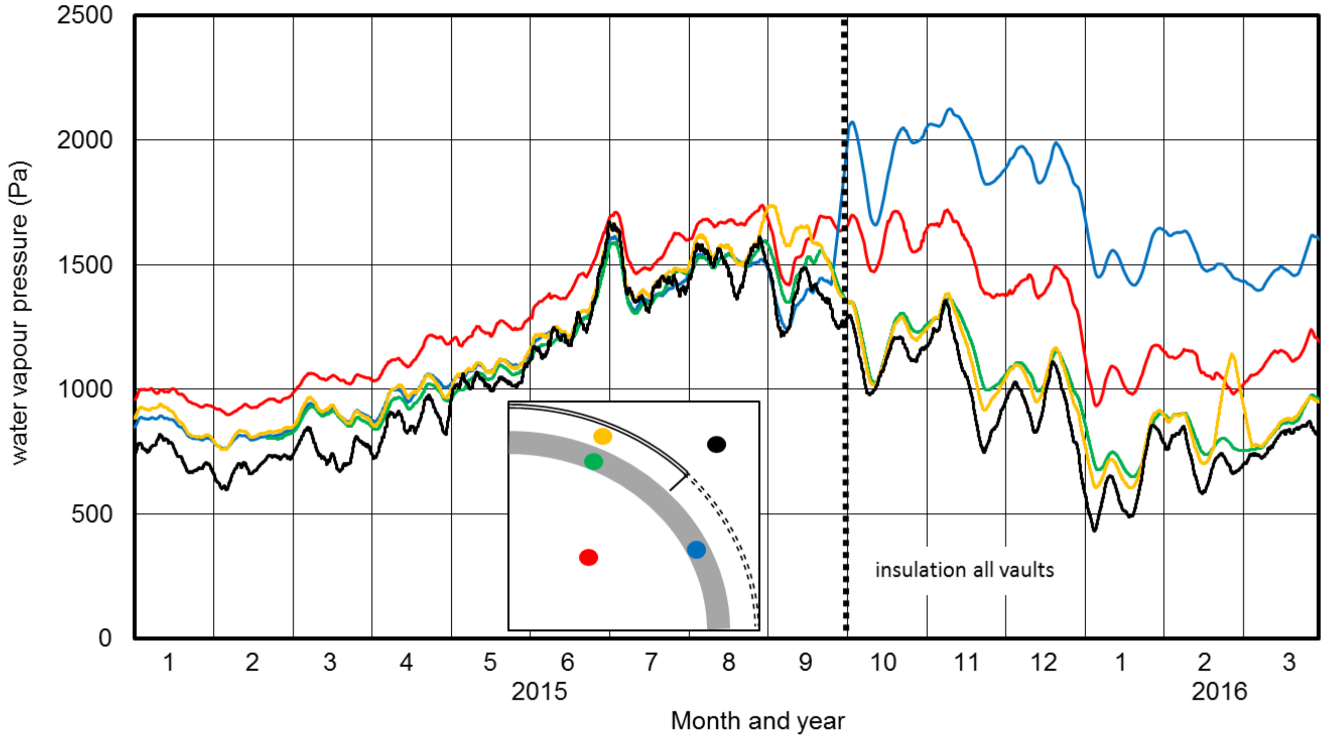

Figure 5. Water vapour pressure calculated from temperature and RH

3.4 ENERGY

The annual use of electricity is given in table 2. The first column gives the actual consumption and the third column gives the corrected values according to the degree days of the year. The deviation from the corrected five-year average is given in the last column. The use of electricity includes the heating and lighting of the church and a small building for toilets and an office for the church ward. The heating season is from 1 April to 31 March the following year. The energy consumption for the year 2015/2016 was equal to the average of the five previous years. The reason was possibly that the inside temperature was kept 2-5 °C higher than in the previous years in order to dry out the surplus of moisture from the vaults. This would increase the loss by transmission. The heat loss by ventilation was also higher, because the doors were kept open most days for some hours to remove the surplus of humidity. The U-value of the wet perlite mortar would be higher than the dry mortar, which also contributed to an increased heat loss. Further monitoring in the next winter is needed to demonstrate the performance of the vault insulation under dry conditions. For future projects it is advised to apply the mortar in summer and rely on solar heating for drying through the attic.

Table 2. Annual enery consumption

Year	*Actual electricity use (MWh)*	*Degree days correction*	*Corrected electricity use (MWh)*	*Deviation from five years average*
2010/2011	49,6	1.08	45,9	-22 %
2011/2012	46,7	0.83	56,3	-4,3 %
2012/2013	55,4	1.02	54,9	-6,6 %
2013/2014	54,4	0.76	71,8	22 %
2014/2015	50,0	0.81	61,4	4,4 %
2015/2016	55,0	0.92	59,6	1,0 %

4. CONCLUSIONS

A mortar mixed of perlite and slaked lime was applied to the vaults of the medieval church in Annisse, DK. A thickness of 100 mm was laid out with a trowel in one layer. An additional layer of 10 mm lime mortar with cattle hair was applied on top to improve the mechanical resistance. The thermal conductivity of the mortar was 0.08 W/m K, and the water vapour permeability was similar to that of brick. Condensation did not occur at any time, even with a vapour pressure difference of 500 Pa between the nave and the attic. The insulation will not be harmful to a sound vault structure. The energy consumption was not reduced the first year compared to a five years average. This was because the inside temperature was raised and the ventilation was increased to dry out moisture from the vaults. The thermal diffusivity of a wet mortar was also higher than of a dry material. Further monitoring is needed to demonstrate the performance of the vault insulation under dry conditions.

5. ACKNOWLEDMENTS

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6. REFERENCES

[1] J. Maia et.al. Laboratory tests and potential for thermal insulation plasters. Proceedings of the 6th International Building Physics Conference, IBPC 2015. Energy Procedia 78 (2015) 2724 – 2729

[2] B. Lorenza et al. Thermal insulating plaster as a solution for refurbishing historic building envelopes: First experimental results. Energy and Buildings 95 (2015) 86–91

[3] T.K. Hansen. Thermal insulation of vaults in Danish medieval churches. Master Thesis. DTU Civil Engineering, Copenhagen, 2015